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A Perspective on Canadian Windpump Technology

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TABLE OF CONTENTS

		Page
1.0	INTRODUCTION	1
2.0	SCOPE OF TECHNOLOGY	1
	2.1 Types of Systems	1
	2.2 Sizes of Systems	2
3.0	STATUS OF CURRENT WINDPUMP TECHNOLOGY	2
	3.1 Rotors	2
	3.2 Drivetrains	3
	3.3 Pumps	4
	3.4 Controls	5
	3.5 System Engineering	5
4.0	RESEARCH PERFORMERS AND TEST FACILITIES	5
5.0	RECOMMENDATIONS FOR WINDPUMPS TECHNOLOGY DEVELOPMENT	6
6.0	SUMMARY AND CONCLUSIONS	8

A PERSPECTIVE ON CANADIAN WINDPUMP TECHNOLOGY

M.S. Chappell

1.0 INTRODUCTION

Most Canadian windpump technical activity is concentrated in Southern Alberta. There is both a continuing and expanding domestic market for windpumps ranging from small farm-scale units for cattle watering to very large units suitable for regional irrigation applications. There is strong potential-user interest from farmers, local co-ops, native bands, and provincial agencies responsible for irrigation and drainage of very large areas of land. An increasing interest is being shown by wetlands preservation agencies and other environmental/ecological groups.

There is significant export potential to mid-western United States, and ultimately huge worldwide potential for appropriate windpump technology in developing countries, perhaps with support from domestic aid programs/agencies. The Brace Research Institute, Montreal, Quebec, is active in development of various technologies appropriate to third world applications, including windpumps. A windpump test facility has been established at Lethbridge, Alberta, to aid in the development and evaluation of Canadian windpump technology.

2.0 SCOPE OF TECHNOLOGY

2.1 Types of Systems

The technology of current windpumps is basically that of the pre-depression North American windpump, i.e., the high-solidity multi-blade rotor, mechanical drivetrain, and reciprocating pump. However, some new configurations are being developed, often to meet particular system requirements. Types of systems include:

Traditional Pumpers - relatively efficient drivetrain, system efficiency improved by using variable stroke to maximize performance. Reciprocating pumps for most heads/flows are commercially available.
Examples: WIND BARON, WILKES CAM

Air-lift (bubbler) Systems - relatively inefficient but suited to drainage applications (where the well may go dry) and deep well pumping relatively immune to damage by freezing. Semi-remote WECS/pump location is possible.

Compressor unloading controls permit use of low solidity (low starting torque) higher efficiency rotor.
Examples: MAVERICK, BOWJON

Electrically-coupled Systems - relatively efficient drivetrain; readily suited to separation of pump and wind turbine; permits use of high speed, low solidity (low starting torque) rotor that has higher aerodynamic efficiency; energy storage possible for certain on-demand loads; centrifugal pumps can be used.
Example: WINCHARGER

Savonius Systems - avoids need for orientation and for furling; rugged; potentially inexpensive; shaft speeds appropriate to reciprocating or vane pumps.
Example: GRAHAM

Photovoltaic Systems - Though expensive, very small systems of this type are attractive because of their "solid state" nature, and PV-pumpers have already made inroads into export (aid) markets.
Example: CAMBRIAN

2.2 Sizes of Systems

Capacities range from small (<5 m rotor dia.) machines with maximum pumping rates of 1-50 L/s to very large (>15 m rotor dia.) machines with maximum pumping rates of 200-500 L/s. In general there are two categories of pumping duty:

(1) low (<10 m) head/high volume
(2) high (>30 m) head/low volume

Small units are available for both duty categories, but the very large units are intended for low head/high volume applications.

3.0 STATUS OF CURRENT WINDPUMP TECHNOLOGY

3.1 Rotors

HIgh solidity multi-blade rotors with high starting torque are used to overcome positive displacement pump loads. The maximum efficiency or power coefficient $C_{p\ max}$ for the rotor is usually between 0.25 and 0.3 and occurs at a tip speed ratio (TSR) between 1.0 and 1.5. Runaway TSR is generally less than 2.0 so lost-load overspeed protection is somewhat inherent.

Recent developments based on delta-blade technology have shown tial for somewhat higher rotor $C_{p\ max}$ (0.35 to 0.4) at TSR ~ 1.8. This is equivalent to high-efficiency low-solidity rotor performance with the added advantage (for pumping applications) of high standstill torque.

Low-solidity, high-speed rotors used on most small air-lift and electrically coupled systems have performance characteristics similar to electrical generation systems. Rotors have $C_{p\ max}$ of 0.3 to 0.4 at TSR ~ 8 to 10 reflecting some performance penalty of low Reynolds number caused by the small size of most units. In general the C_p-TSR characteristics of low solidity rotors are much broader in absolute terms than the typically peaky (narrow TSR range) characteristics of high solidity rotors, though peak C_p's may be similar for both rotor types.

Far less work has been done on VAWT water pumpers. In general, Darrieus VAWT's are unsuitable for direct drive water pumping due to their low starting torque. Some development has been done on electrically-connected Darrieus pumpers by the US Department of Agriculture using a Canadian 50 kW VAWT. Performance characteristics of Savonius rotors have been well explored both analytically and experimentally. Maximum C_p's are generally ~0.2 at TSR ~ 1.0, however, other system simplicities are sometimes sufficient to offset this low performance.

3.2 Drivetrains

The traditional, and simplest, windpump drivetrain comprises a crank either geared to, or mounted directly on, the rotor shaft, and a long connecting rod attached directly to the piston of the reciprocating pump. Variants of this basic concept include various counterweighting and balancing arrangements to reduce cyclic loads on the structure, gearing to increase force at reduced frequency for high head pumps, mechanisms to permit (slightly) remote siting of the turbine from the pump, and various devices to alter pump stroke in order that TSR can be maintained at the $C_{p\ max}$ value over a broad range of windspeeds. Efficiency of these mechanical drivetrains is high (typically 0.90 to 0.95) and reliability is good.

Pneumatic "drivetrains" are inherent to air-lift systems. Compressor losses, line losses, and poor energy conversion to pumped fluid combine to give quite low drivetrain/pump efficiences (typically 0.2 to 0.4) but may be offset in some applications by more advantageous siting of the wind turbine (remote from the well). A disadvantage of air-lift systems is the requirement for a well of much greater depth to provide the lift.

Hydraulic drivetrains have been receiving recent attention from both HAWT and VAWT windpump manufacturers. Efficiencies of pump/lines/motor or cylinder systems are typically 0.5 to 0.6 and reasonable separation is possible between turbine and pump. Suitably chosen industrial or agricultural-grade components should result in high reliability, providing scrupulous cleanliness is maintained during assembly and maintenance.

Electrically-coupled systems permit the greatest separation of turbine and pump and hence the greatest opportunity for system optimization. Drivetrain efficiency is relatively high, typically 0.75 to 0.85 overall, and reliability is good. Usually electrically-coupled systems use rotary pumps of either centrifugal or vane type.

A potential advantage of hydraulic, air-lift, and electric drivetrains, especially for small windpumps, is that they may not require a gearbox even for relatively low power high rpm rotors. For larger units, however, a speed increasing gearbox may be required for the electrical systems, thereby reintroducing cost, weight, and maintenance penalties. Some good experience has been recorded with toothed-belt pulley transmissions for small units.

3.3 Pumps

Wind turbine driven pumps generally must handle significant quantities of foreign matter suspended in the pumped fluid. Erosion of valves, glands, and other sealing/rubbing surfaces is a major design consideration.

The traditional pump for use in a wind turbine pumping system is a single reciprocating piston pump located at ground level for shallow well applications, or submerged near the bottom of deep wells. Both single and double acting units are in service; the former being more common. Volumetric and energy efficiency of mid-size (10 L/s) units are typically 0.85 and 0.75, respectively, but both values are strongly dependent on pump condition. Reliablility is generally good for well-developed units specifically intended for windpump applications. Many 40 to 60 year old units are still fully functional. Larger, double-acting or twin-cylinder reciprocating pumps have been developed for large diesel or electric pumping stations. Performance is comparable to the smaller units but fewer applications have not yet provided the long experience for high technical maturity (and hence high reliability) systems. One of the largest units being developed is the twin cylinder single-acting DELTX WP-50 pumps, each with ~ 1.5 m bore and a maximum stroke of ~ 1.2 m.

The air-lift pump works by injecting air partway down the well tube. Hydrostatic pressure of the water surrounding the well tube forces the

lower density air-water mixture to rise to ground level. Efficiency of the pump alone is low (typically 0.3 - 0.5); however, such systems are often used in drainage applications where the well may be pumped dry periodically.

Rotary pumps, both centrifugal and vane type, have been used on windpumps with mechanical, hydraulic, and electric drivetrains. Centrifugal pumps are best suited to the higher speed electric and hydraulic drives. Vane pumps tend to be somewhat more efficient than centrifugals (typically 0.75 vs. 0.60) but are generally less tolerant of foreign matter suspended in the pumped fluid.

3.4 Controls

The purpose of a windpump control system is to maximize power output at low and moderate windspeeds, to limit power generation at high windspeeds, and to ensure safe operation under all conditions. Typical control functions include orienting the rotor into moderate winds and furling (or yawing) the rotor progressively out of the wind as windspeed exceeds certain limits. Rotor design often allows for runaway rpm as this is seldom excessive due to the C_p-TSR characteristics of high solidity rotors. (This is not so for most low solidity rotors such as used for electrically-coupled or air lift systems.) In some windpump systems controls are provided to adjust output and thereby maintain TSR close to the value for $C_{p\ max}$. Such drivetrain adjustments may be made mechanically or via hydraulic servo systems. Simplicity and reliability are the prime prerequisites for a good windpump control system: the latter to minimize required maintenance, and the former to ensure the typical owner-operator can perform any maintenance required.

3.5 System Engineering

The matching of components within the windpump system and the optimization of the complete system for its specific application are equally important to achieving high component efficiencies. Cost effectiveness, notefficiency per se, is the overall design goal. It is often cheaper to increase performance by using a slightly larger rotor than to significantly increase the complexity of the major components or control system in an attempt to increase overall system efficiency.

4.0 RESEARCH PERFORMERS AND TEST FACILITIES

For many years work on water pumping windmills suitable for developing countries has been carried out at the Brace Research Institute of McGill

University, Montreal. These "appropriate technology" systems have been focussed towared local manufacturing capabilities and indigenous materials.Plans for home-built or village-built systems are available.

Several agents and distributors for non-Canadian waterpumpers have existed in Southern Alberta for many years. Interest in developing Canadian windpump technology escalated in the early 1980's among dealers and manufacturing firms in the Calgary and Lethbridge areas. Engineering firms such as Norwest Energy Services, Jensen Engineering, and ABAX became involved in windpump technology development. John Kentfield of the University of Calgary, Calgary, Alberta, conceived the delta-blade rotor based on very low speed characteristics of the supersonic delta airfoil. A 3.3 m diameter model was tested in the NRC 9.2 m × 9.2 m wind tunnel and gave a maximum C_p of 0.37, about 20% better than current windpump rotors. ABAX, a Calgary engineering and steel fabrication firm, received substantial support from the Alberta/Canada Energy Research Resources Fund (A/CERRF) to design, construct, and test a large prototype delta-blade windpump based on Kentfield's research. This prototype, which incorporates a slightly more advanced rotor design than that tested by NRC, was erected on ABAX's property in Calgary in 1983 and incorporated a variable-stroke controller to maintain C_p near its peak value over a broad range of windspeeds. Debugging and evaluation of this 16 m diameter unit continues under A/CERRF sponsorship and with some technical and financial participation from NRC.

In 1982, with contributions from Farming for the Future, TransAlta Utilities, and A/CERRF, Alberta Agriculture established the Lethbridge Windpump Test Station (LWTS) where basic performance of several farm-scale windpumps can be measured under realistic field conditions. To date about a dozen different machines have been evaluated, including several traditional units as well as prototype and production versions of various newer concepts described earlier.

Among the windpumps currently under test at LWTS is a Canadian-manufactured version of an international windpump design created in the United Kingdom. Also active in international windpump technology development are CWD in the Netherlands who hosted a major UN/World Bank Global Workshop on Windpump Technology in March 1984.

5.0 RECOMMENDATIONS FOR WINDPUMPS TECHNOLOGY DEVELOPMENT

To date, federal government support of Canadian windpump technology development has been minimal. Major initiatives have been taken by the Alberta Government both in stimulating the establishment of the LWTS and in

encouraging the industrial initiative of provincial windpump manufacturers. Achievements so far sustain the potential for Canadian technology in both domestic and export markets. Canadian International Development Agency officials have confirmed interest in incorporating **proven** Canadian wind pump technology into third-world aid projects. Thus, it is both logical and necessary to include windpump technology within the scope of the Canadian wind energy research and development program. Indeed, the first major step in this direction has been taken by the Renewable Energy Branch of Energy, Mines and Resources Canada (REB/EMR) through their agreement for $50K/a to support the LWTS.

In general, Canadian windpump technology development could proceed along the following lines:

Activity	Govt level support	Major Performers	Ancilliary Performers
Research	Fed	Universities (Calgary, Lethbridge)	Lethbridge Windpump Test Site
Development & Testing	Fed/Prov	Lethbridge Windpump Test Site	Manufacturers
Demonstration & Industrial Support	Prov/Fed	PRO's Manufacturers	Users

In the Research, Development, and Testing sectors the following projects would have immediate technical benefit to Canadian windpump technology:

- Creation of a user-friendly, PC-based component optimization analysis for matching rotor, pump, and load characteristics to achieve best overall system performance.

- Completion and evaluation of a variable-stroke controller to optimize system efficiency over significant ranges of windspeed, particularly for very large windpumps for irrigation and pumped-storage hydroelectrc applications.

- Design and construction of a (portable?) dynamometer to drive and measure volumetric and energy efficiencies of pumps over a range of flows and heads.

- More detailed performance data on traditional, delta-bladed, and Savonius rotors and their compatibility to typical drainage and irrigation pump characteristics.

- Better understanding and documentation of non-traditional windpump characteristics such as air-lift and electrically or hydraulically coupled systems.

- Definition of test circuit and instrumentation design parameters to increase accuracy and reduce problems caused by vastly different dynamic characteristics of wind, rotor, pump, and test circuit.

In the Demonstration and Industrial Support sector the following projects and objectives should be addressed in the near future.

- Quantitative market potential analyses by unit volume flow and head for various applications and wind regimes.

- Selection, realization, and documentation of meaningful typical demonstration projects.

- Participation with Brace Research Institute in evolving alternative materials and fabrication techniques to allow at least partial indigenous production and maintenance of Canadian-designed windpumps in developing countries.

- Participation with CIDA/IDRC in selected overseas demonstrations when testing and domestic demonstrations have proven certain systems.

Clearly, not all these topics must be addressed from "square one." A constructive initial step would be to hold a specialist workshop where participants would contribute to defining exactly what is known and available in these (and other) areas, and then to establish what further activity is required, and how and by whom it could be achieved.

6.0 SUMMARY AND CONCLUSIONS

1. It is generally accepted that a significant domestic market exists for both small and large scale windpumps; however, quantitative data in various flowrate/head/windspeed categories are needed to guide component designers and system engineers toward near-term markets.

2. The nucleus of a small but significant Canadian windpump industry exists, predominantly in Alberta, comprising agents and dealers for

non-Canadian designs, restorers of old farm windpumps, and designers/-manufacturers of new Canadian windpumps.

3. Certain innovative Canadian designs (e.g., ABAX delta-blade rotor and variable stroke controller) have shown promise and deserve further support to complete development and for demonstration and commercialization.

4. Basic testing facilities for windpumps have been established at Lethbridge, Alberta. However, this site needs further technical capability to properly assist and advise windpump manufacturers and users on component and system performance.

5. Coordination of technical requirements within the fledgling Canadian windpump industry could substantially enhance cost-effectiveness of both public- and private-sector R&D effort and expenditure.

6. A significant but unquantified market for Canadian windpump technology and systems exists in foreign industrialized and third world countries. Equipment for such applications must be thoroughly proven and very reliable. In addition to direct private-sector marketing, indirect application of Canadian windpump technology via CIDA/IDRC programs should be pursued.